Chapter 01. Introduction

1.1 Preamble

There has been rapid growth in technology and population in recent decades. The world population has reached about 8 billion in 2023 from 5 billion in 1990. An increase of 47% (Worldometers, 2023). The growth in technology has also contributed to an increase in the world's eco-footprint. The increase in population and technological growth has caused the depletion of natural resources while increasing waste generation at both domestic and industrial levels. In recent times, the majority of the research is pursued to obtain environmentally sustainable solutions. This includes the development of methods to Reduce, Reuse and Recycle waste generated. One of the major contributors to waste generation is the poultry sector. The waste from poultry includes carcasses and feathers. Although some of the feathers are disposed of by incineration and poultry feed, the majority of this waste ends in landfills. The chicken feathers are biodegradable but the presence of keratin makes the process very slow. The methods presently available take a lot of time and energy and also lead to the release of toxic gases at the time of the process.

To avoid this loss of time and energy and deterioration of the environment globally, extensive research work is being carried out to utilize chicken feather waste and convert them into sustainable and environmentally compatible solutions. Like other natural fibers, chicken feathers are being explored and used for reinforcing composites due to their environmentally compatible nature, fully biodegradability, non-toxic, renewable, lightweight, low processing cost, and low density. A composite is a material made from two or more (mostly fiber and matrix) with different physical or chemical characteristics, when mixed in known proportion, produces a material with distinct characteristics different from the individual materials. The individual materials retain their inherent characteristics while interacting at the interfaces.

Extensive research on the preparation, fabrication, and properties of polymer matrix composite replacing synthetic fibers with natural fibers like jute, bamboo, rice husk, sawdust, chicken feather fiber, coconut fiber, etc. are being carried out. Significant research work is also being carried out to replace petroleum derived polymers with biopolymers/bioplastics derived from starch, cellulose, or any other natural resource.

The majority of the work in the preparation of components by composites is carried out manually or automatically by moulding.

Various techniques presently existing are:

- Hand Lay-up
- Spray Layup
- Casting
- Potting
- Encapsulation
- Injection Moulding
- Resin Transfer Moulding
- Vacuum/Pressure Bag Moulding
- Centrifugal Casting
- Rotational Moulding
- Pultrusion
- Continuous lamination
- Continuous Filament Winding
- Cold Pressing
- Hot Pressing
- Vacuum Impregnation

The major limitation of these composite manufacturing methods is:

- Complex shapes are difficult to manufacture.
- The tooling cost is high if the no of parts manufactured is very less.
- Adhesion failure between layers due to manual mismatch.
- Avoiding bubbles, air entrapment and unwetted interface requires utmost care.
- In these methods, bulk solidification/vitrification occurs, which requires a longer duration of curing.
- In the case of manual methods, the homogeneity/consistency of layer height is dependent on the stability of the person's hand, which sometimes causes the mechanical characterization unpredictable.

3D printing is a technology, which is now being explored to overcome these limitations. Three-dimensional (3D) printing is a technology to manufacture material structures through a layer-by-layer approach (Hwang et al., 2015). Additive manufacturing (AM) is defined as the process in which an object is produced by joining several layers with specific thicknesses using different bonding technologies.(Wahlström & Sahlström, 2016; Yang et al., 2017). Additive manufacturing(AM) and the 3D printing process is based on extrusion, the material being "selectively dispensed through a nozzle or orifice" (ISO / DIS 17296-1, 2015).

The most common and well-developed system for additive manufacturing is commonly known as fused deposition modeling (FDM). In this process, a heated thermoplastic is extruded through a heated die and selectively deposited into a stable, flat surface in layers. The deposited material bonds with the previous layer via glass transition bonding due to the heat input of the new materials (Turner et al., 2014; Turner and Gold, 2015).

FDM is operated by using an extruded thermoplastic filament and extruding it through a hot print head. This process is also termed Fused Filament Fabrication (FFF). The limitation of FFF is that the raw material should be in filament form only (Popescu et al., 2018). The filament is usually made up of thermoplastics such as Poly-lactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS). For the ease of making the filaments, additives such as plasticizers are used. Composite filaments are manufactured with different blends of polymers and reinforcement materials. In the majority of the applications carbon fibers derived from natural resources (animals and plants) have been used. The size of the reinforcements usually varies from a few microns to 100 microns. Few reported attempts are available for continuous fiber reinforced filaments. Another limitation of the existing process of filament manufacturing is the fiber size. Short fibers or long fiber reinforced filaments for 3D printing are not available. Presently 3D printing option is not available to manufacture composites with short or long fibers. This has led to the need of developing a short fiber composite filament extruder.

1.2 Objectives

The objectives of the present work are as follows

- To study the suitability of Chicken feather fiber (CFF) as reinforcement in composite materials through a systematic literature review.
- To design and manufacture Composite Filament Extruder for short fiber reinforcements.
- To manufacture filament using CFF as reinforcement and Poly-Lactic Acid as matrix material.
- Characterization study of filament manufactured.
- To manufacture samples by the sandwich method using CFF and Biopolymer (PLA).
- Comparative study of filament manufactured and samples prepared by the sandwich method.

1.3 Research Methodology

For fulfilling the objectives of the present study following research methodology was adopted:

- ➢ Carry out a literature review of using CFF as reinforcement in composites
- ➢ Design and Manufacturing of Short fiber reinforced composite filament extruder
- ➢ Pilot experiments will be performed to establish the working range of process parameters of the extrusion process of composite CFF/PLA Filament

- Manufacture short CFF reinforced PLA composite filament.
- Investigate and characterize the manufactured composite filament.
- Manufacture CFF/PLA reinforced composite samples using the sandwich method
- Result analysis
- Compare the mechanical characteristics of the sample prepared by the sandwich method with the composite filament
- Thesis writing.

1.4 Thesis Organization

The thesis consists of seven chapters. Chapter 1 gives a brief introduction to natural fibers and the need to use them in manufacturing composites. It discusses briefly various techniques used for manufacturing composites. It presents the need for developing a short CFF-reinforced composite filament for additive manufacturing using the FDM technique. In the end, the chapter presents the objective of the investigation and the research methodology adopted to accomplish them.

Chapter 2 presents the bibliometric review and state-of-the-art review of the literature available in the research domain. Existing literature in natural fibers, CFF, matrix materials, biocomposites, 3D printing of composites, and, the design of filament extruders have been discussed and research gaps have been identified.

Chapter 3 reports on the materials used in the present investigation. It presents the characteristics of CFF and Poly-Lactic Acid. Along with this, the chapter also presents the preprocessing done on the constituent materials before utilizing them for the preparation of composite filament.

Chapter 4 presents the design and manufacture of a short fiber-reinforced filament extruder. It discusses the preparation of the samples considering the Taguchi method to design experiments. It also presents the manufacture of composite samples using the sandwich method for an alternate method of manufacturing CFF/PLA composites using a 3D printer.

Chapter 5 narrates the characterization techniques used for the composite filament. It describes the procedure, standards, and parameters set for carrying out the tensile test, DSC, TGA, DTA, FTIR, chemical solubility, and electrical resistance tests.

Chapter 6 presents a discussion of the results of various tests. It also interprets the results and attempt has been done to present the justification for the behavior and characteristic of the composite filament.

Chapter 7 focuses on the conclusion and recommendation for the prospects of research in the field of extruder design, optimizing the characteristic of CFF/PLA composite filament, and application of the composite filament. The organization of the entire thesis is shown in Figure 1-1.

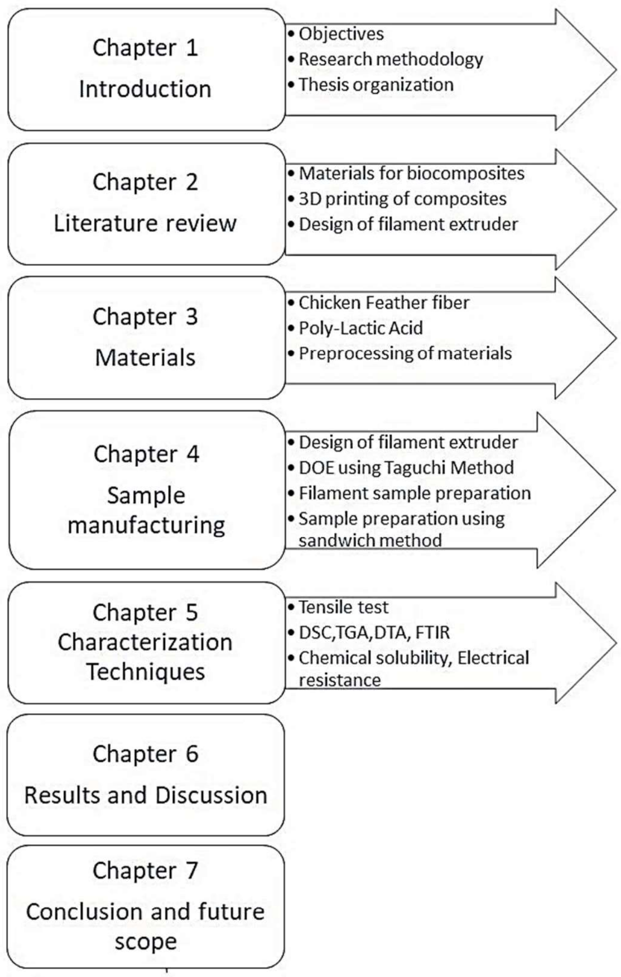

Figure 1-1 Organization of the Thesis.